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MF PROPAGATION: non-reciprical ionospheric propagation on multi-hop paths

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Summary

At medium frequencies, polarisation coupling loss occurs on multi-hop paths when waves reflected from the Earth's surface re-enter the ionosphere. Under some circumstances the coupling loss changes significantly when the direction of propagation is reversed.

Issued under the authority of

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Research Department, Engineering Division,
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MF PROPAGATION: NON-RECIPROCAL IONOSPHERIC PROPAGATION ON MULTI-HOP PATHS

P. Knight, M.A., Ph.D., M.I.E.E.

This report draws attention to the fact that multi-hop ionospheric propagation is in general non-reciprocal.[1] It is shown that significant differences in transmission loss may occur at m.f. between two directions of propagation on certain paths.

At m.f. the extraordinary wave is heavily attenuated and only the ordinary wave need be considered. When the elliptically-polarised wave which emerges from the ionosphere is reflected from the Earth's surface between hops, its power density is reduced and its polarisation is changed. Polarisation coupling loss occurs when the wave re-enters the ionosphere* if the polarisation of the ground-reflected wave differs from that of the ordinary wave which it excites. The total reflection and coupling loss is known as intermediate reflection loss and is given in dBs by[2]

$$L = -10 \log_{10} Q \qquad (1)$$

where

$$Q = \frac{|R_V(\cos\psi_1 + jM_1 \sin\psi_1)(\cos\psi_2 - jM_2 \sin\psi_2) + R_H(\sin\psi_1 - jM_1 \cos\psi_1)(\sin\psi_2 + jM_2 \cos\psi_2)|^2}{(1+M_1^2)(1+M_2^2)} \qquad (2)$$

R_V and R_H are the Fresnel plane-wave reflection coefficients for vertical and horizontal polarisation respectively. M is the axial ratio of the ordinary wave polarisation ellipse, positive values of M corresponding to anticlockwise rotation when looking in the direction of propagation, and ψ is the tilt of its minor axis, measured in an anticlockwise direction from the horizontal. Subscripts 1 and 2 refer to the incident and reflected waves respectively.

If the direction of propagation is reversed the following changes must be made in Equation (2).

M_1 is replaced by $-M_2$
M_2 is replaced by $-M_1$
ψ_1 is replaced by $-\psi_2$
ψ_2 is replaced by $-\psi_1$

The changes of sign occur because the wave is now viewed from the opposite direction, the actual directions of rotation of the polarisation ellipses and their tilt angles being unchanged. The effect of these changes is to replace all the terms in Equation (2) except R_V and R_H by their complex conjugates.

If R_V and R_H are real (or imaginary) the value of Q is unchanged, but if either is complex the loss will, in general, change if the direction of propagation is reversed. The biggest change is likely to occur when waves are reflected from land at the Brewster angle because R_V is then a negative imaginary quantity. Little change is to be expected when waves are reflected from the sea because R_V and R_H for sea water approximate closely to real quantities at all angles of incidence.

Computations show that the greatest differences between the two directions of propagation occur on east-west land paths in temperate latitudes, the greater loss occuring when waves propagate from east to west. Fig. 1 shows computed losses for east-west paths at 65° dip latitude at 0·5 and 1·5 MHz for land and sea reflection. It will be seen that sea-reflection paths are almost reciprocal, but losses may differ considerably with land reflections. Figs. 2 and 3 show how losses vary with direction of propagation and dip latitude when waves are reflected at 7° to the horizontal from land of the same conductivity as before. Losses in the northern and southern hemispheres are identical.

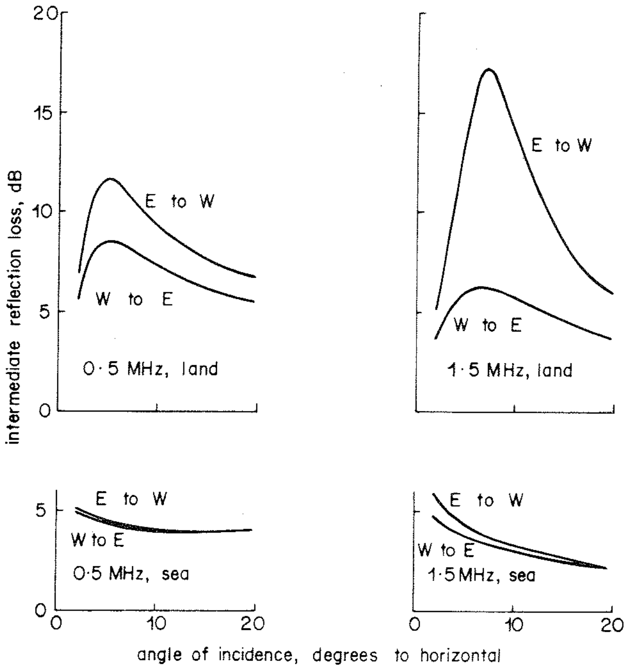

Fig. 1 - Intermediate reflection loss on east-west paths at 65° dip latitude
Gyromagnetic frequency 1·25 MHz
Ground constants assumed for land paths:
dielectric constant, 4 conductivity, 10 mS/m

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* Polarisation coupling loss also occurs when the transmitted wave enters the ionosphere for the first time, and when it leaves the ionosphere for the last time.

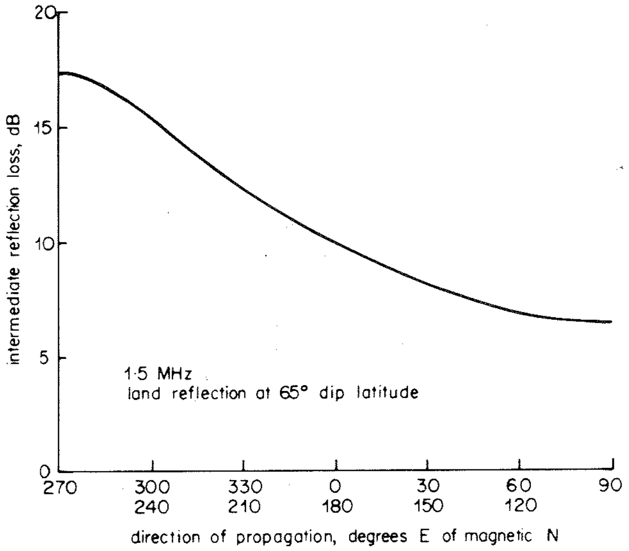

Fig. 2 - Variation of intermediate reflection loss with direction of propagation

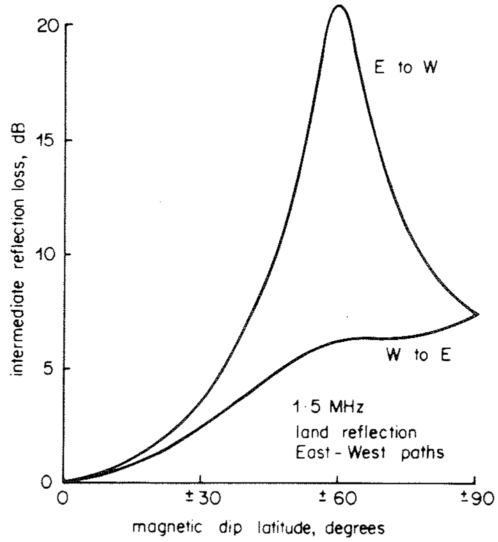

Fig. 3 - Variation of intermediate reflection loss with magnetic-dip latitude

Fig. 4 is an attempt to explain the difference qualitatively. The wave is assumed to be incident at the Brewster angle, so that the phase of its vertical component is retarded by 90° on reflection. It will be seen that the reflected wave has the same sense of rotation as the ordinary wave on paths towards the east and therefore excites the ordinary wave efficiently. On paths towards the west, however, the reflected wave has the opposite sense of rotation and the coupling loss is larger. Fig. 4 applies to the northern hemisphere; similar diagrams show that the greater loss also occurs in the southern hemisphere when propagation is towards the west.

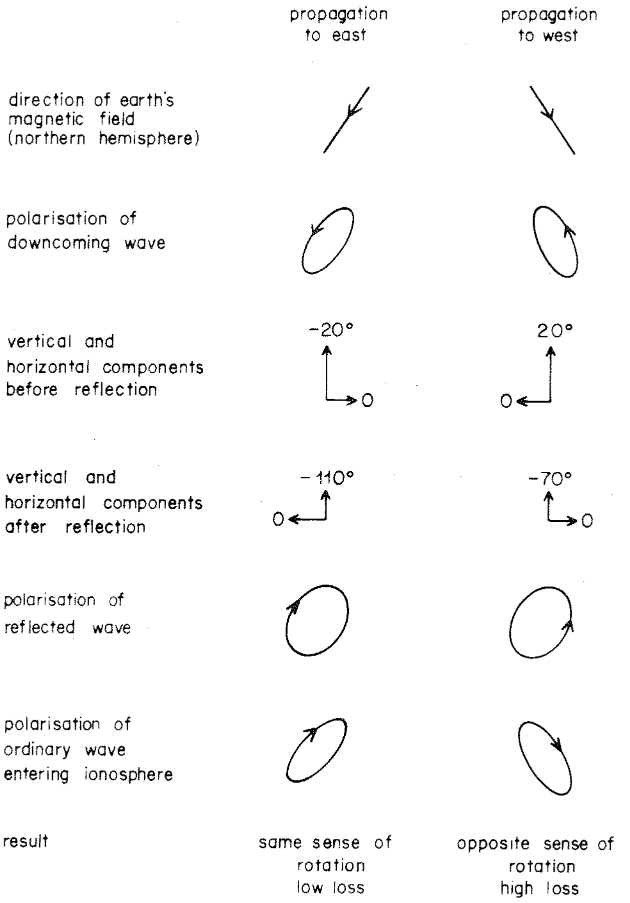
propagation to east
propagation to west
direction of earth's magnetic field (northern hemisphere)
polarisation of downcoming wave
vertical and horizontal components before reflection
-20°
0
20°
0
vertical and horizontal components after reflection
-110°
0
-70°
0
polarisation of reflected wave
polarisation of ordinary wave entering ionosphere
result
same sense of rotation low loss
opposite sense of rotation high loss

Fig. 4 - Physical explanation for non-reciprocal propagation

Reflection is assumed to be from land at the Brewster angle, with $R_V = -j0{\cdot}5$ and $R_H = -1$. The diagrams show polarisation ellipses as seen when looking in the direction of propagation.

The difference between the two directions of propagation is most likely to be observed on paths which are just beyond the range of the 1-hop mode; at this distance (2000 – 2500 km) the two-hop mode is reflected at angles near the Brewster angle. Differences twice as large may occur on 4000 to 5000 km paths; here the three-hop mode predominates and is reflected twice at angles near the Brewster angle. Unfortunately, there is no direct evidence for the existence of non-reciprocal propagation and a carefully-controlled experiment would be required to demonstrate it.

References

1. BRADLEY, P.A. *and* BRAMLEY, E.N. 1971. Wave polarisation and its influence on the power available from a radio signal propagated through the ionosphere. Part 3 – Two-hop modes. *Proc. Instn. elect. Engrs.*, 1971, **118**, 9, pp. 1190 – 1196.

2. PHILLIPS, G.J. *and* KNIGHT, P. 1965. Effects of polarisation on a medium-frequency sky-wave service, including the cast of multi-hop paths. *Proc. Instn. elect. Engrs.*, 1965, **112**, 1, pp. 31 – 39.

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